

Electrostatic Charging of Polymers by Particle Impact at Low Pressures

C.I. Calle¹, J.G. Mantovani², C.R. Buhler³, M.D. Hogue¹, A.W. Nowicki⁴, and E.E. Groop¹

¹NASA, Kennedy Space Center, FL, USA

²Florida Institute of Technology, Melbourne, FL, USA

³Swales Aerospace, Merritt Island, FL, USA

⁴Dynacs Engineering, Kennedy Space Center, FL, USA

Abstract: Studies of the electrostatic interaction between micrometer-sized particles and polymer surfaces are of great interest to NASA's planetary exploration program. The unmanned landing missions to Mars planned for this decade as well as the possible manned missions that might take place during the second decade of this century require a better understanding of the electrostatic response of the materials used in landing crafts and equipment when exposed to wind-blown dust or to surface dust and sand particles. We report on preliminary experiments designed to measure the electrostatic charge developed on five polymer surfaces as they are impacted simultaneously by Mars simulant particles less than 5 micrometers in diameter moving at 20 m/s. Experiments were performed in a CO₂ atmosphere at 10 mbars of pressure using a particle delivery method that propels the particles with contact. Experiments were also performed in dry air at atmospheric pressures using a pressurized particle delivery system. The five polymer surfaces, commonly used in space applications, were chosen so that they span the triboelectric series.

Key words: Electrometer; Mars; Electrostatics at low pressures; Contact electrification; Frictional charging; Polymer charging

1. Introduction

Studies seeking to understand the electrostatic interaction between micrometer-sized particles and spacecraft surfaces are of crucial importance to NASA's exploration of Mars. Results from the Viking and Pathfinder missions to the planet show that Martian dust is less than a few micrometers in diameter [1-3]. Although the mechanism for dust loading into the atmosphere is not well known, both Viking and Pathfinder observed considerable airborne dust [2]. Winds, which on Mars can reach speeds of 30 m/s, transport these particles over long distances. Triboelectric charge can be generated between colliding particles in this fairly chaotic environment. Charged and uncharged particles moving in these dust storms will charge the surfaces of landing spacecraft and their equipment, producing unwanted potentials. The fundamental understanding of this interaction is

still an unresolved problem in physics [4,5]. Experiments to characterize this interaction are a first step in the development of a more complete understanding of this phenomenon.

We report on preliminary experiments designed to measure the electrostatic charge developed on five polymer surfaces impacted by dust particles. These experiments were done at partial simulated martian conditions. Experiments were also performed at low humidities and atmospheric pressure.

2. Experiments

The granular material used in these experiments was obtained by grinding JSC Mars 1 simulant particles [6] down to 5 μ m in diameter. Several electrometer configurations were designed for these experiments. A multisensor electrometer [7,8], an instrument for a future Mars landing mission jointly developed at the Jet Propulsion

Laboratory and at our laboratory at the Kennedy Space Center, was used in several of our experiments to detect the charge developed on five different polymers and served as the parent technology for other electrometer designs.

The electronics for the electrometer used in these experiments (Fig.1) is based on the design of the multisensor flight electrometer. This multisensor electrometer contains 5 triboelectric sensors each capped with insulators. The insulators are Fiberglass/epoxy G-10, Lexan™, Teflon, Rulon J™, and Lucite. The insulators have a diameter of 6.35 mm and a thickness of 2.01 mm and are mounted to a titanium housing in a row configuration (Fig. 2). A prototype of a second electrometer with an aerodynamic configuration is being developed for these experiments [9].

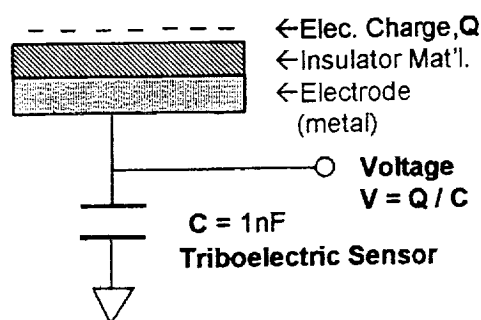


Figure 1. Charge to voltage converter. The circuit gain is 0.25 nC per volt.

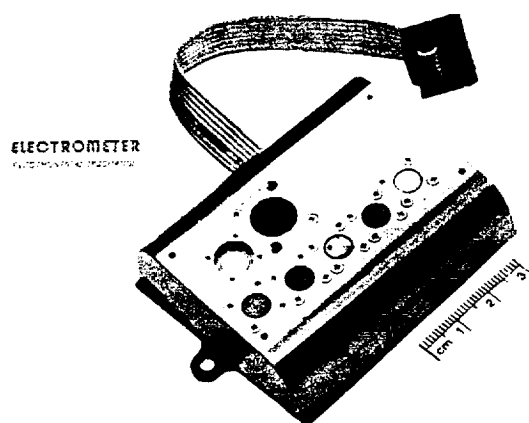


Figure 2. Multisensor electrometer with 5 insulators.

2.1. Particle Impeller Experiments

The martian atmospheric environment was partially simulated in a 0.12 m³ vacuum chamber. The chamber was set at a pressure of 10 mbars and backfilled with carbon dioxide, since 95% of the Martian atmosphere is CO₂. A device to propel submillimeter-size particles without contact at speeds up to 20 m/s at pressures ranging from 5 mbars to 1 bar was developed for these experiments. JSC Mars-1 simulant particles, 5 μm in diameter, were baked at 150 °C for at least 24 hours to remove moisture before being placed in a vacuum chamber.

Winds with speeds of 20 m/s were generated in the chamber with the particle impeller. Dry simulant particles having a total mass of about 1 gram were propelled by the moving CO₂ or air molecules to the electrometer. The particles were believed to have achieved the same speed as that of the wind. Particle impact on the polymers was uneven due to aerodynamic considerations. Two cases were distinguished, light and heavy coating of dust of the polymers. Figure 3 shows charge generation and decay on the five polymers in the multisensor electrometer for light coating and figure 4 shows charging of fiberglass for heavy and light coating.

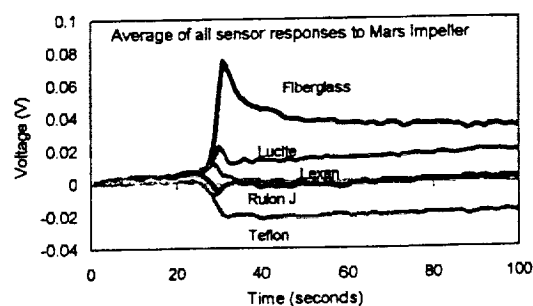


Figure 3. Average simultaneous response of five polymers to windborne particles using the particle impeller

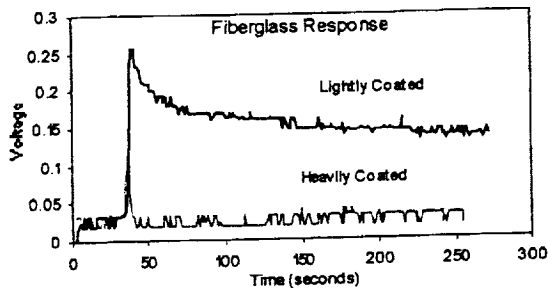


Figure 4. Charge generated on Fiberglass for light and heavy coating.

2.2 Compressed Air Particle Delivery System Experiments

A pressurized particle delivery system was constructed to propel Mars simulant particles at atmospheric pressures and low relative humidities. Fluidized martian simulant particles were propelled with compressed dry air toward each one of the polymers in the multisensor electrometer at speeds of 30 m/s within a closed chamber at 5% relative humidity. Since the average vertical flux vortices near Mars Pathfinder during a dust devil event was $0.5 \text{ g/m}^2/\text{s}$ [10], the flow rate was adjusted to deliver $1 \text{ g/m}^2/\text{s}$. The particles travel through a grounded metal tube 3.9 mm in diameter. The average charge to mass ratio of the simulant as it came out of the tube was measured to be $2.8 \text{ } \mu\text{C/g}$. By comparison, the charge to mass ratio of simulant free-falling particles was -26.6 nC/g .

Figure 6 shows results for the five polymers in the multisensor electrometer. Compressed air is blowing through the system when the electrometer is turned on at time zero. Between 50 and 500 s, dust flows through the system. At $t = 500 \text{ s}$, the dust and the air flow are turned off.

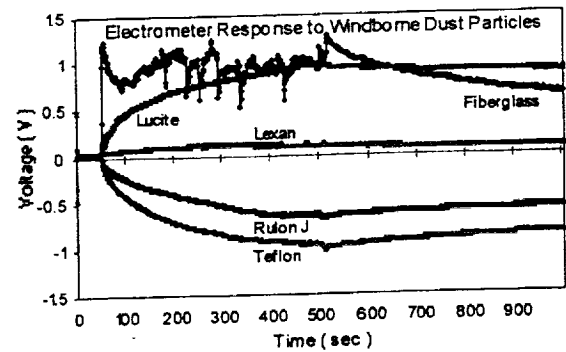


Figure 5. Simultaneous response of five polymers to windborne particles using the compressed air particle delivery system at atmospheric pressure.

3. Discussion

3.1 Particle Impeller Results

Figure 3 shows the average response for 30 runs. The five polymers were simultaneously impacted by the particles to varying degrees due to the narrow cross section of the dust flow. Fiberglass charged the most positively. Using the 0.25 nC/V gain (Fig. 1), the maximum charge generated on fiberglass was 19 pC . Table 1 shows the average maximum amount of charge produced on all five polymers.

Table 1. Average Maximum Charge

Polymer	Charge (pC)
Fiberglass	19
Lucite	2.5
Rulon J	-1.3
Lexan	-2.5
Teflon	-5

Responses with light and heavy coating of the polymers with particles could be differentiated in most cases. Figure 5 illustrates this situation for fiberglass. Light covering generates a maximum charge of 55 pC followed by a characteristic charge decay. In the heavy coating case, the initial contact of the particles with the polymer surface produces a sharp peak that rises to 17 pC and rapidly discharges. A possible

explanation would be that the first particles colliding with the polymer surface bounce off, producing the separation required to build up the electrostatic potential observed. A subsequent avalanche of particles returns most of these charged particles to the surface. The particles were observed sticking to the surface after the experiment ended. Since no separation occurred, the transferred charge between particle and polymer was measured as neutral by the electrometer. Both of these behaviors were observed several times.

3.2 Compressed Air Particle Delivery Results

The grounded curved metal tube delivering the high speed particles from the container, as well as the particle-particle interactions as the particles traveled along the tube, produced an average charge to mass ratio of $2.8 \mu\text{C/g}$. In contrast, particles dropped from a metal container into a Faraday cup had an average charge to mass ratio of -26 nC/g . These charged particles collide with each one of the five polymers in the multisensor electrometer producing the charges shown in Fig. 6. The figure shows the average values of 10 runs for each polymer.

The ordering in the magnitude of the charge as well as the sign of the charge generated on the polymers is similar to what was obtained with the Particle Impeller. With the compressed air system, particles collide with the polymers for 450 seconds, whereas with the particle impeller, all particles are delivered to the polymers in about 5 seconds. Figure 6 shows the charge build up that results. It can be seen that fiberglass, which tends to acquire a large positive charge, as seen also in Figs. 4 and 5, tends to discharge rapidly.

4. Conclusions

These experiments show that windborne particles can charge insulator surfaces which our electrometer can detect. More aerodynamic electrometer designs should improve the sensitivity as more particles will collide with the sensors.

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